Laminar, Three-dimensional Open Jet

1 Introduction

This case provides a description for three-dimensional laminar open jet flow (bottom constrained plane) with constant properties. A passive scale mixture fraction is activated; inflow velocity is a constant value absent of any profile.

2 Theory

The three-dimensional geometry for this tutorial is captured in Figure 1. Here, the cylindrical domain is defined by the vertical height, H, the outer diameter, D_o, and inlet pipe diameter d_o and specified to be 50 cm, 15 cm, and 1.0 cm, respectively.

The bottom plane contains an inflow and bottom wall while the side and top are represented as an open boundary condition where static pressure is specified.

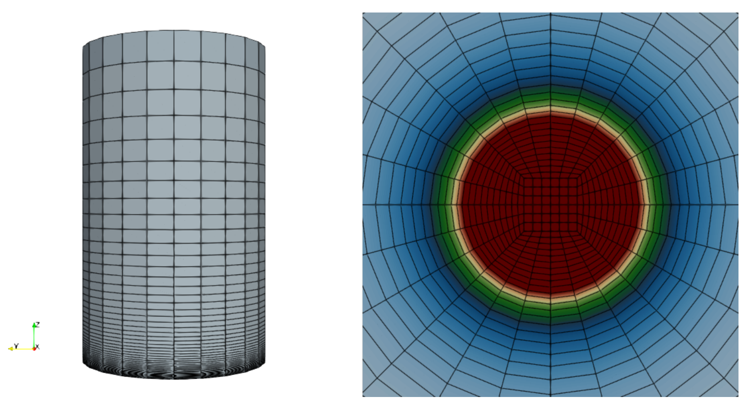


Figure 1: Three-dimensional open jet flow configuration. Shadings on the right side of the figure are for mixture fraction, Z.

The variable-density low-Mach equation set is defined by the continuity and momentum equation,

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_j}{\partial x_j} = 0. \tag{1}$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_j u_i}{\partial x_j} - \frac{\partial \sigma_{ij}}{\partial x_j} = 0. \tag{2}$$

In the above equation, ρ is the fluid density and u_j is the fluid velocity. The stress tensor is provided by

$$\sigma_{ij} = 2\mu S^*_{ij} - P\delta_{ij}, \tag{3}$$

where the traceless rate-of-strain tensor is defined as

$$S^*_{ij} = S_{ij} - \frac{1}{3}\delta_{ij} S_{kk} = S_{ij} - \frac{1}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}.$$

In a low-Mach flow, the above pressure, P, is the perturbation about the thermodynamic pressure, P^{th}.

For the open jet configuration of interest, a passive scalar transport equation for mixture fraction is activated and defined as the mass fraction of species that originates from the inlet boundary condition,

$$\frac{\partial \rho Z}{\partial t} + \frac{\partial \rho u_j Z}{\partial x_j} + \frac{\partial q_j}{\partial x_j} = 0, \tag{4}$$

where the diffusive flux vector is given by $q_j = \frac{\mu}{Sc}\frac{\partial Z}{\partial x_j}$. Here, the Schmidt number is given as a function of density and mass diffusivity D, as $Sc = \frac{\mu}{\rho D}$.

It is noted that although the domain is cylindrical and axisymmetric in nature, we present the equation set in a Cartesian coordinate system.

2.1 Analytical Profiles

Similarity approximations are available for the three-dimensional open jet configuration.

3 Results

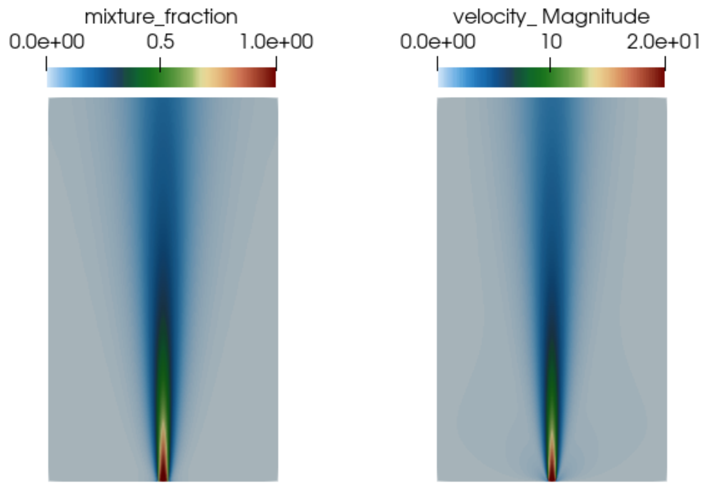
Let us test a simulation in which the Reynolds number based on inlet diameter and inlet velocity comprised of air is 100. By constraining the Reynolds number, density, viscosity, and inlet pipe diameter, the inflow velocity (u_{inlet}) in the z-direction is obtained via,

$$u_{inlet} = \frac{\mu Re}{\rho d_o}. \tag{5}$$

Values for density, viscosity, and inflow velocity are 1.0e-3 g/cm^3, 2.0e-4 $dyne-s/cm^3$, 20 cm/s, respectively.

3.1 Simulation Specification and Results

For the $Re = 100$ configuration, the simulation is run using a Hex8 (linear hexahedral) mesh. In Figure 2, mixture fraction and magnitude of velocity shadings are provided for the specifications provided above.



(a) (b)

Figure 2: Planar mixture fraction (a) and velocity magnitude (b) shadings for the $Re = 100$ jet case.

In Figure 3, the centerline normalized mixture fraction and vertical velocity are presented. Finally, to illustrate the self-similar radial profiles for the downstream locations ($\frac{z}{d_o}$ of 5, 10, and 20), see Figure 4. For this procedure, the maximum velocity that occurs on the centerline is captured at each downstream location. The radial half length, r_h, is defined as the radial position where the velocity is one-half the peak value on the centerline. The self-similar jet profile is strongly correlated past $\frac{z}{d_o}$ of five - well beyond the core collapse of the jet.

4 Discussion Points

There are several interesting activities associated with this sample case including the following:

- Ensure that the underlying model suite is well understood.
- Explore the mesh and input file associated with this case.

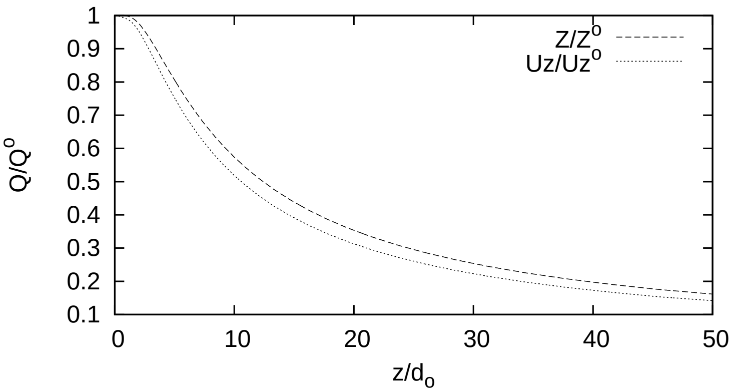


Figure 3: Normalized velocity and normalized-mixture fraction centerline plot for the $Re = 100$ jet case.

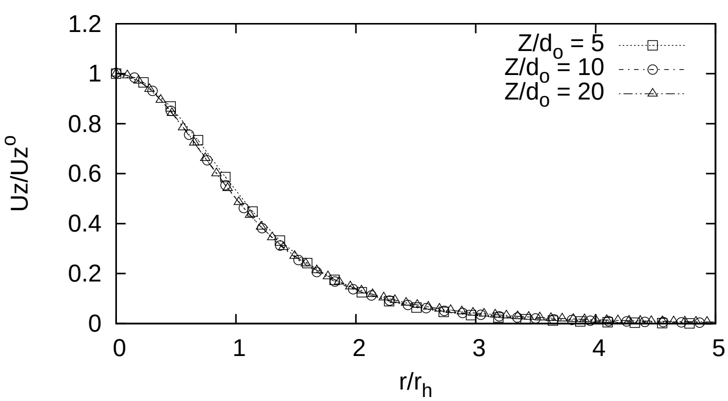


Figure 4: Normalized vertical velocity as a function of normalized radial distance (by radial half distance, r_h) for the $Re = 100$ jet case.

- Explore the removal of the bottom wall plane in favor of an open boudnary condition with and without total pressure specification.
- Comment on the resulting core collapse distance and the self-similar behavior.